LITTER DECOMPOSITION AND SOIL RESPIRATION RESPONSES TO FUEL-REDUCTION TREATMENTS IN PIEDMONT LOBLOLLY PINE FORESTS

Mac A. Callaham, Jr., Peter H. Anderson, Thomas A. Waldrop, Darren J. Lione, and Victor B. Shelburne[1]

Abstract—As part of the National Fire and Fire Surrogate Study, we measured the short-term effects of different fuel-management practices on leaf litter decomposition and soil respiration in loblolly pine stands on the upper Piedmont of South Carolina. These stands had been subjected to a factorial arrangement of experimental fuel-management treatments that included prescribed burning, selective thinning, and a combination of thinning and burning. First-year results indicated that decomposition of leaf litter was significantly slower in thinned stands than in burned or control stands, and that nitrogen dynamics were variable over time in thinned and burned stands relative to controls. Soil respiration was lower in burned stands than in control or thinned stands, possibly due to fire-induced reductions in potentially mineralizable carbon pools in the forest floor. These results suggest that carbon and nitrogen dynamics are significantly altered by thinning and burning, but these alterations are manifested in fundamentally different ways.

INTRODUCTION

The need for a comprehensive strategy for managing forest fuels to minimize the risk of wildfires on Federal, State, and private lands is increasingly apparent. This is true for forested systems across North America, including forests in the Southeast that were historically regulated by frequent low-intensity fires, but where long-term fire suppression has resulted in unprecedented fuel accumulations. Prescribed fire and selective thinning are practices commonly used to manage fuel loads in forests with heavy fuel loads. Although these fuel-load management practices may be effective for mitigating wildfire risk, comparatively little is known about how these treatments may affect other components of system function. In addition to reducing fuel loads, these practices are likely to affect numerous other ecosystem characteristics, including pool sizes and flux rates of carbon (C), nitrogen (N), and other nutrients.

Net storage or loss of C in ecosystems is of critical interest to land managers, as atmospheric concentrations of CO_2 continue to rise far beyond levels observed in recent earth history (Schlesinger 1997), raising concerns about how these CO_2 concentrations may detrimentally influence global climate patterns. Some proposals for mitigation of future CO_2 production rely on rewarding the long-term fixation and storage of C in biological or other pools with "carbon credits." Thus, information about how landscape-scale applications of thinning or prescribed fire influence C dynamics should be of interest to land managers, environmentalists, industrialists, and politicians alike. Current estimates suggest that about 10 percent of the total C pool in the atmosphere is fixed by vegetation, cycled through soil, and passed back into the atmosphere as soil respiration every year (Schlesinger and Andrews 2000). Landscape-scale changes in land use or land management; e.g., increased use of prescribed fire or thinning, have the potential to alter regional patterns of fixation or respiration, and thus could result in either increased net storage of C in terrestrial sinks or net losses of C to atmospheric pools.

Fire effects on soil fertility have been studied extensively for Coastal Plain forests, but much of this work has focused on total soil organic matter and not necessarily on fluxes of C or N (e.g., McKee 1991, Moehring and others 1966, Wells 1971). Exceptions include the work of Schoch and Binkley (1986) and Bell and Binkley (1989), which examined studies of N dynamics in postfire soils on the South Carolina Coastal Plain. Management effects on pools and fluxes of C and N in fire-prone systems have begun to be studied in western forests of the United States (e.g., Baird and others 1999, Choromanska and DeLuca 2002, Kaye and Hart 1998), but this type of study has been rare in southeastern Piedmont pine forests. Objectives for this study were to determine short-term effects of prescribed fire, selective thinning, and a combination of thinning and burning on C and N fluxes in decomposing leaf litter, and C flux as soil respiration in pine forests of the Piedmont.

MATERIALS AND METHODS

Site Description

We conducted this study on the Clemson Experimental Forest located on the upper Piedmont of South Carolina (82°50′W., 34°40′N.). Climate at the site is mild, with average temperatures of 25.5 °C in July and 5 °C in January, and average annual precipitation of 121 cm. Vegetation at the site is dominated by southern pines with loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia pine (*P. virginiana* Mill.) all well represented in the overstory. Understory vegetation is mixed hardwood with red maple (*Acer rubrum* L.), flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), and various oaks (*Quercus* spp.) making up the majority of trees, and blueberry (*Vaccinium* spp.) as the dominant understory

[1] Research Ecologist, USDA Forest Service, Southern Research Station, Athens, GA 30602; Biological Scientist, USDA Forest Service, Southern Research Station, Research Triangle Park, NC 27709; Research Forester, USDA Forest Service, Southern Research Station, Clemson University, Clemson, SC 29632; and Graduate Student and Associate Professor, Department of Forest Resources, Clemson University, Clemson, SC 29632, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

shrub. There are also numerous species of herbs, grasses, and vines present in these forests. Soils on the Clemson Experimental Forest are generally classified as Typic kanhapludults or Typic hapludults, with the majority falling into Pacolet, Madison, Cecil, and Tallapoosa soil series.

Experimental Design

Experimental units used in this study were arranged in a completely randomized block design with three replicate plots in each of three treatments. Treatments included prescribed fire, selective thinning, a combination of thinning and burning, and an untreated control. Fire treatments were applied as stripped head fires in April and May of 2001, and all thinning was conducted by feller buncher to basal area of 80 square feet per acre in the winter of 2000–01. For the thinning-plus-burning combination treatment, fires were applied in April of 2002 on plots where slash from the thinning was burned along with accumulated fuels. All treatments were blocked by stand age: the first block was pulpwood-aged timber (15 to 20 years), the second block was a mixture of pulpwood and sawtimber (20 to 30 years), and the third block was predominantly sawtimber-aged (30+ years). Each experimental replicate was approximately 6 to 10 ha in area, and at least 36 permanent sampling points were established on a grid at 50-m intervals.

Leaf Litter Decomposition

Litter bags were used to determine rates of litter decomposition in each of the fuel treatments examined in the experiment. Pine litter was collected on tarps suspended over ground level in a stand of loblolly pine that had been attacked by southern pine beetle. This allowed us to collect uniform-quality senesced pine litter in large quantities before it came into contact with the forest floor. Approximately 5 g of this litter was placed inside a bag made of fiberglass window-screen mesh (aperture approximately 0.2 mm), and in November 2000, 12 of these bags were placed on the forest floor at 5 grid points within each experimental replicate. Because fire had not yet been applied to the thin-plus-burn plots, only three treatments were used for this part of the study (thin, burn, and control). One bag was collected from each grid point every 2 months (for a total of 5 bags from each treatment unit or 45 bags per sample date). Contents were removed, dried at 55 °C for at least 48 hours, and weighed to determine mass lost due to decomposition. Carbon and N concentrations for initial litter material and bimonthly litter bag samples were determined by micro-Dumas combustion on a Perkin-Elmer 2400 Series II CHNS/O analyzer.

Soil Respiration

We measured soil respiration at five locations within each experimental replicate, roughly corresponding (within 15 m) to the locations of the litter bags. Respiration was measured using a Licor 6400 infrared gas analyzer with a soil chamber attachment. We selected one live tree, 25 to 35 cm in diameter, nearest the permanent grid point within the experimental replicate, and measured soil respiration at two distances (50 cm and 150 cm) from the base of the selected tree. We took the average of the two observations at each location, for a total of five observations for each treatment unit.

Data Analysis

Because litter bags were only deployed in three treatment types, we analyzed litter decomposition data by one-way analysis of variance (ANOVA) with burn and thin as treatment variables. Soil respiration data were analyzed by two-way ANOVA with burn and thin as main effects variables; i.e., interactions between burn and thin were also examined. Averages of observations for all variables made within the same experimental unit were used for ANOVA procedures; thus, N = 3 for each treatment for all analyses.

RESULTS AND DISCUSSION

Litter Decomposition

The most basic measure of litter decomposition, mass loss over time, revealed no significant differences in absolute mass lost between treatments in this study. However, another useful expression of mass loss is often achieved by calculating rate of decay (k) as the slope of a regression line for percent of litter mass remaining vs. time (Coleman and Crossley 1996). In our study, this calculation showed that the rate of decay for litter in thinned stands was slower (0.077 d^{-1}) than in burned or control stands (0.088 and 0.093 d^{-1}, respectively) (fig. 1). Although this difference is small, when projected on an areal basis, slower decomposition rates in thinned stands would result in larger accumulations of litter on the soil surface over time.

When individual elements were analyzed in litter from the litter bags, our data suggested that C was lost at a similar rate in all three treatments. There was no significant difference in the proportion of original litter C remaining between control stands and stands that had burned or thinned (fig. 2A).

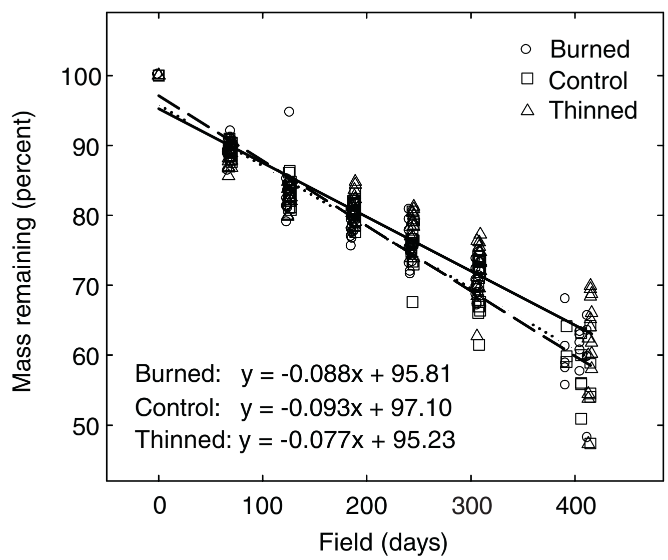

Figure 1—Linear regressions for determination of decay constants (k = percent mass loss d^{-1}) for pine litter in fire and fire surrogates study plots at Clemson Experimental Forest, SC. Each symbol represents an individual litter bag. Triangles and solid line represent bags from thinned stands; circles and dotted line represent bags from burned stands; squares and dashed line represent bags from control stands. Linear equations are shown for each treatment as $y = k(x) + b$, where *y* = estimated percent mass remaining, *k* = decay constant, *x* = days in the field, and *b* = y-intercept.

There were significant treatment effects on the dynamics of N in decomposing leaf litter. N concentrations were highly variable in material from litterbags in thinned units and burned units, whereas N concentrations were less variable over time in control units (fig. 2B). Litter from thinned and burned units had significantly lower concentrations of N on dates 3 and 5, but these differences were not observed on dates 4 and 6. The variable concentrations of N in leaf litter in the thinned and burned stands may be related to temperature and moisture conditions in the litter at the time of collection. Previous studies demonstrate that N and other nutrients can move into or out of decomposing litter as conditions become more or less favorable for decomposer organisms (e.g., Blair and Crossley 1988, Blair and others 1992). We did not directly measure litter temperature or moisture content, but thinning and burning both reduce canopy cover and remove all or part of the litter layer. Thus, temperature and moisture at the soil surface (and therefore N content of litter) are likely to be more variable in these stands than in controls.

Litter quality also influences rates of decomposition, and the ratio of C to N (C:N) in litter materials is commonly used as a measure of litter quality. In general, litter with higher C:N is considered to be of lower quality, as this material is more difficult to metabolize for decomposer organisms (Swift and others 1979). In this study, we observed significant treatment differences in C:N of decomposing litter. There was no difference in C:N for the first two sampling dates, but by the third sample date a trend of higher C:N in litter from thinned stands had emerged (fig. 2C). The difference between thinned stands and control stands was statistically significant for dates 3, 5, and 6. Additionally, on the fifth and sixth dates, we observed significantly higher C:N in litter from burned stands relative to controls (fig. 2C). Higher C:N ratios in litter from thinned stands partially explain the observed trend of slower decomposition of litter in these stands noted above (fig. 1). Given higher C:N in litter from burned stands, future sampling may reveal a slower rate of litter decomposition in these stands as well.

Soil Respiration

Soil respiration data indicated that burning significantly reduced the rate of CO_2 efflux from plots in this experiment (fig. 3). This pattern was observed in plots that were burned only, as well as in plots that were thinned and then burned. Thinning alone had no effect on CO_2 efflux relative to controls. The combustion of organic matter in forest floor litter (Oi) and duff (Oe + Oa) is possibly responsible for the reduction in respiration, as the loss of this organic matter represents a coincident loss of at least some portion of the potentially mineralizable C pool. This idea is supported by the findings of Shelburne and others (in press) that indicated a reduction in concentrations of Oa horizon soil C in burned stands relative to controls in the same study. Another explanation may be the higher soil temperatures and lower soil moisture in burned stands relative to thinned or control stands. The blackening of the soil surface that occurs with prescribed fire may result in increased absorption of solar energy as well as increased soil temperatures and soil drying. There is a well-known relationship between temperature, moisture, and soil respiration, with respiration rates decreasing at high temperature and low moisture (Singh and Gupta 1977). Decreased root respiration from trees in burned stands is another possible cause for the observed patterns of decreased respiration in burned stands. This pattern would be observed if the fire had damaged roots or aboveground tissues such that root respiration would be reduced.

Thinning; i.e., reducing canopy cover, could also result in increased solar energy reaching the forest floor, increasing temperature, but the removal of the litter layer is much less uniform with thinning than with prescribed fire. Because the litter layer provides a buffer against diurnal fluctuations in temperature and humidity, forest floor in thinned stands may

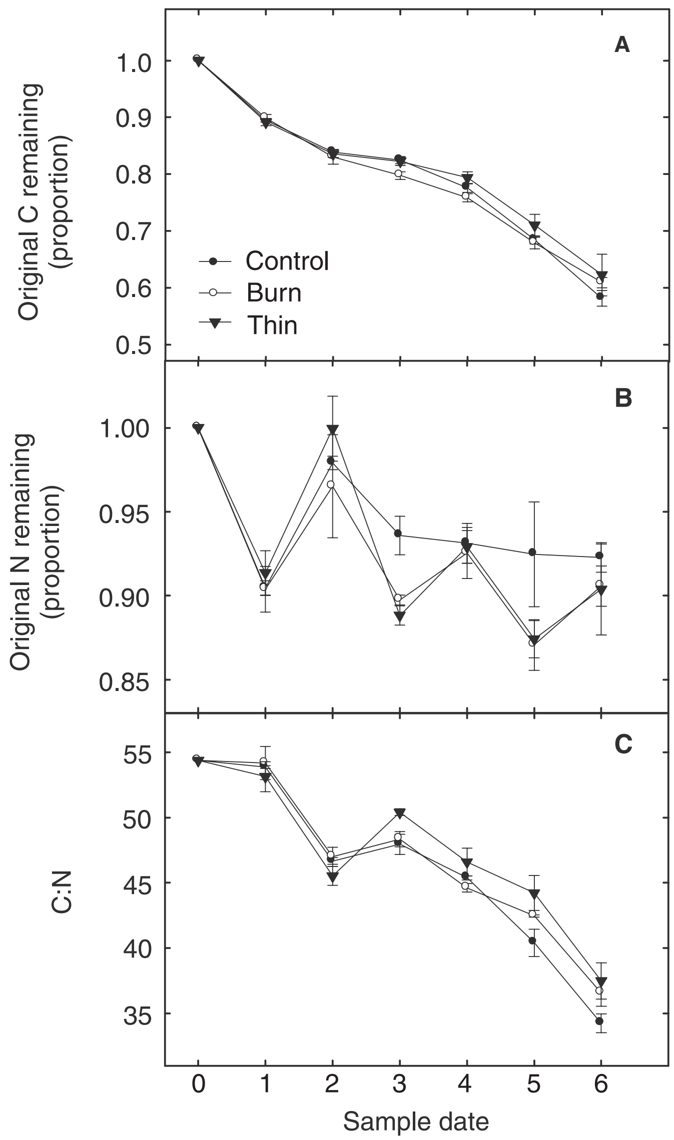

Figure 2—Leaf litter decomposition in fire and fire surrogates study plots at Clemson Experimental Forest, SC. (A) Proportion of original carbon remaining, (B) proportion of original nitrogen remaining, (C) carbon to nitrogen ratio [carbon (C), nitrogen (N)]. For all plots values are means (n = 3), and error bars indicate standard error, open circles represent bags from burned plots, closed triangles represent bags from thinned plots, and closed circles represent bags from control plots.

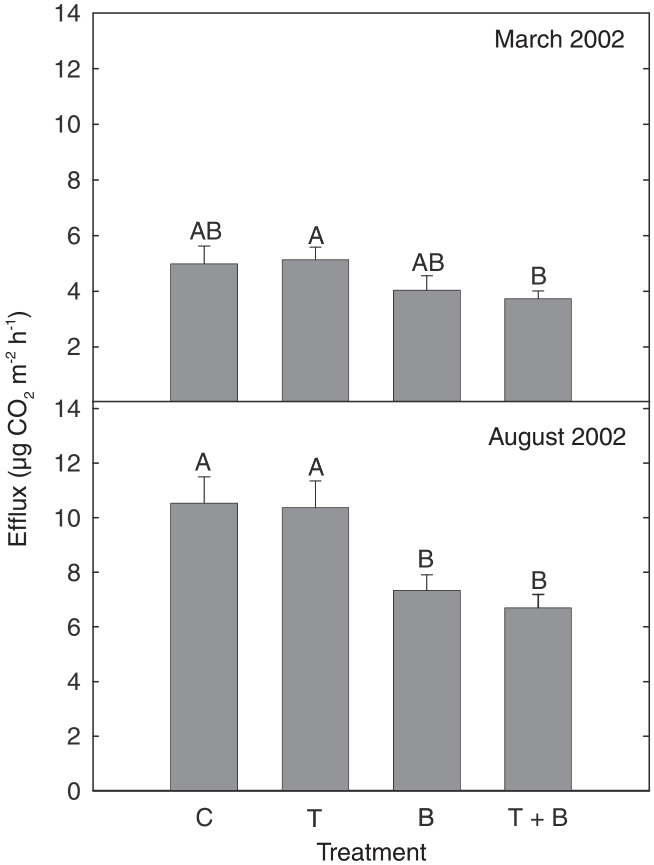

Figure 3—Soil respiration (CO_2 efflux) from fire and fire surrogates study plots at Clemson Experimental Forest, SC. Bars are means (n = 3), and error bars indicate standard error. Treatments are C = control, T = thinned, B = burned, and T + B = thinned and burned. Bars with different letters were significantly different ($p < 0.05$).

not experience much warmer or drier conditions than control stands. Thus, the difference in respiration rates between burned and thinned stands may be explained by the composition and structure of the forest floor.

CONCLUSIONS

The effects of thinning and burning on C fluxes examined in this study provide evidence that these management practices can have measurable impacts on the movement of C through this system. However, drawing conclusions about what these differences might mean with respect to net loss or storage of C for each management system is problematical. The decreased rates of litter decomposition in thinned stands observed in this study suggest that, at least in the short term, more C would be stored in the forest floor of thinned stands than in unmanaged stands. However, effects of thinning on the fixation of C are not well characterized for our study plots; thus, the net effect of thinning on C storage is not yet known. Likewise, the decreased respiration rates observed in the burned plots suggest the potential for net storage of C as less CO_2 returns to atmospheric pools from soils in burned stands. However, the amount of CO_2 produced by combustion of litter materials during the actual fire event (or reduced fixation of C by plants after fire) may offset any gains due to reduced efflux of CO_2 after the fire. The duration of the reduced respiration will be an important factor in determining the net effect of fire on C storage in these systems. Developing more complete C budgets for these management systems, including vegetation effects, combustion effects, and soil temperature effects on biological activity in soils, should improve our ability to predict cycling and storage of C and dynamics of N.

ACKNOWLEDGMENTS

This is Contribution Number 31 of the National Fire and Fire Surrogate Project, funded by the U.S. Joint Fire Science Program. The authors wish to thank Helen Mohr, Gregg Chapman, Chuck Flint, and Ross Phillips for assistance in the field, and Corey Babb for assistance in the laboratory.

LITERATURE CITED

Baird, M.; Zabowski, D.; Everett, R.L. 1999. Wildfire effects on carbon and nitrogen in inland coniferous forests. Plant and Soil. 209: 233-243.

Bell, R.L.; Binkley, D. 1989. Soil nitrogen mineralization and immobilization in response to periodic prescribed fire in a loblolly pine plantation. Canadian Journal of Forest Research. 19: 816-820.

Blair, J.M.; Crossley, D.A., Jr. 1988. Litter decomposition, nitrogen dynamics and litter microarthropods in a Southern Appalachian hardwood forest 8 years following clearcutting. Journal of Applied Ecology. 25: 683-698.

Blair, J.M.; Crossley, D.A., Jr.; Callaham, L.C. 1992. Effects of litter quality and microarthropods on N dynamics and retention of exogenous 15N in decomposing litter. Biology and Fertility of Soils. 12: 241-252.

Choromanska, U.; DeLuca, T.H. 2002. Microbial activity and nitrogen mineralization in forest mineral soils following heating: evaluation of post-fire effects. Soil Biology and Biochemistry. 34: 263-271.

Coleman, D.C.; Crossley, D.A. 1996. Fundamentals of soil ecology. San Diego: Academic Press. 205 p.

Kaye, J.P.; Hart, S.C. 1998. Restoration and canopy-type effects on soil respiration in a ponderosa pine-bunchgrass ecosystem. Soil Science Society of America Journal. 62: 1062-1072.

McKee, W.H., Jr. 1991. Long-term impacts of fire on Coastal Plain pine soils. In: Nodvin, S.C.; Waldrop, T.W. Fire and the environment: ecological and cultural perspectives: Proceedings of an international symposium. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 405-413.

Moehring, D.M.; Grano, C.X.; Bassett, J.R. 1966. Properties of forested loess soils after repeated prescribed burns. Res. Note SO-40. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Schlesinger, W.H. 1997. Biogeochemistry: an analysis of global change. 2d ed. San Diego: Academic Press. 588 p.

Schlesinger, W.H.; Andrews, J.A. 2000. Soil Respiration and the global carbon cycle. Biogeochemistry. 48: 7-20.

Schoch, P.; Binkley, D. 1986. Prescribed burning increased nitrogen availability in a mature loblolly pine stand, Forest Ecology and Management. 14: 13-22.

Shelburne, V.B.; Boyle, M.F.; Lione, D.J.; Waldrop, T.A. [In press]. Preliminary effects of prescribed burning and thinning as fuel reduction treatments on the Piedmont soils of the Clemson Experimental Forest. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. Asheville, NC: U.S. Department of Agricultue, Forest Service, Southern Research Station.

Singh, J.S.; Gupta, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. Botanical Review. 43: 449-528.

Swift, M.J.; Heal, O.W.; Anderson, J.M. 1979. Decomposition in terrestrial ecosystems. Berkeley, CA: University of California Press. 372 p.

Wells, C.G. 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. In: Prescribed burning symposium; Proceedings. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 86-99.